ASIAEX Reverberation Studies

Peter G. Cable
BBN Technologies
Old Mystic Mill, 11 Main Street
Mystic, CT 06355-3641
Phone: (860) 446-4923 fax: (860) 245-0406 email: pcable@bbn.com

LONG-TERM GOALS

This research is intended to establish an understanding of the scattering mechanisms operating in low frequency reverberation in shallow water typical of continental shelf regions. The intent is to distinguish among the effects of different scattering components, such as sediment interface and layering roughness, fluctuations in sediment properties, and discrete scattering components, and to quantify their relative contributions. This research is being performed with David Knobles (ARL:UT) and Eugene Dorfman (BBN, Cambridge) with these efforts together forming an integrated research activity.

OBJECTIVES

Using a normal mode propagation model and a physics-based bottom scattering coefficient [1 and cited references] in a two stage simulated annealing optimization [2], the specific objectives of the work will be to invert low frequency reverberation and transmission data obtained during the summer 2001 ASIAEX in the East China Sea to recover the bottom scattering strengths associated with volume, surface and sediment layering. The ultimate intent of this research is to infer mechanisms of low frequency bottom scattering in shallow water.

APPROACH

Experimentally, the determination of bottom scattering strength in shallow water is complicated by the multipaths associated with the proximate boundaries: scattering strengths must be extracted from reverberation measurements, which necessitates some integration over the incident and scattering angles involved. As a consequence, comparisons of scattering strength models and measurements must account for experimental constraints and limitations that intrinsically convolve propagation to and from the scattering site with the scattering kernel. The motivation for turning to a high-resolution global inversion method, such as simulated annealing, is that it can be used to efficiently search the large parameter space physically describing transmission to the bottom scatterers and the scattering process to obtain optimal parameter values to extract scattering strength.

Detailed modeling of propagation for the shallow water channels with sand-silt bottoms has indicated that beyond about 5-10 km ranges, propagating energy is confined to bottom grazing angles less than the critical angle. In consequence, beyond the indicated ranges, acoustic bottom penetration is limited to the evanescent field extending about one wavelength into the bottom. Thus, the proposed mechanism for bottom scattering in these environments is scattering of the evanescent field into the

1. REPORT DATE **30 SEP 2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**
4. TITLE AND SUBTITLE **ASIAEX Reverberation Studies**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **BBN Technologies,,Old Mystic Mill, 11 Main Street,,Mystic,,CT,06355**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This research is intended to establish an understanding of the scattering mechanisms operating in low frequency reverberation in shallow water typical of continental shelf regions. The intent is to distinguish among the effects of different scattering components, such as sediment interface and layering roughness, fluctuations in sediment properties, and discrete scattering components, and to quantify their relative contributions. This research is being performed with David Knobles (ARL:UT) and Eugene Dorfman (BBN, Cambridge) with these efforts together forming an integrated research activity.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

water by roughness at the sediment-water interface and by volume scatterers just below the interface. Volume scatter candidates include fluctuations in sediment density or compressional wave speed and discrete inhomogeneities within the sediment such as shells or rock fragments. In addition, scattering from roughness at near-surfical sediment layer boundaries, observed in some areas such as the New Jersey Shelf, should be included as a candidate component. The theory describing the sediment fluctuation contributors has been developed in the Born approximation [1]. Extension of the theory to include layering roughness and discrete scattering components is also required and will be used to define the parameters needed to obtain a complete determination of bottom scattering strength.

The activities being performed under this research effort have included: (1) preparations for ASIAEX data collection and coordination with seagoing participants in the tests; (2) preparation of initial models for use in the data inversion process and testing by simulations; (3) performance of two stage data inversion (forward propagation and scattering) on ASIAEX data; (4) identification and interpretation of scattering mechanisms from frequency and angular dependence of reverberation; (5) refinement of physical models of scattering process based on inversions; (6) performance of refined inversions employing improved physical models to further quantify scattering mechanisms. Within the overall effort, Peter Cable (BBN) is lead for interpretation of scattering mechanisms, refinement of the scattering model and comparison with other East China Sea bottom scattering measurements. David Knobles (ARL:UT) is lead for determination of transmission characteristics and extraction of bottom geoacoustics from the ASIAEX data; Eugene Dorfman (BBN) and Thomas Yudichak are leads for extraction of bottom scattering strength and its frequency and grazing angle dependence from the ASIAEX reverberation data.

WORK COMPLETED

During FY03 low frequency broadband reverberation data gathered during the ASIAEX East China Sea experiment by Institute of Ocean Acoustics (Chinese Academy of Sciences) investigators under the leadership of Profs. Ji-Xun Zhou (GaTech) and Renhe Zhang (IOA) and obtained by us in April 2002 have been analyzed to obtain bottom scattering strengths and to interpret the results as described in the previous section. The focus of the work during this period has been determination of the dependence of bottom scattering strength on frequency and characterization of the uncertainties associated with the extraction of shallow water scattering strength from reverberation.

Regarding determination of estimation errors, in addition to stochastic variability associated with reverberation measurements, errors in estimation of transmission loss to and from the scattering and uncertainty in source level can result in errors in scattering strength determination. In the analysis of the ASIAEX reverberation data it has been found that the largest source of scattering strength frequency dependence uncertainty arises from persistence of finite amplitude effects associated with the source signal.

An initial report on the frequency dependence of East China Sea bottom scattering strength and effects of source uncertainty was presented at the ASIAEX International Symposium in Chengdu, China, in October 2002. Also three papers on the analysis of East China Sea reverberation data were presented at the First Pan-American/Iberian Meeting on Acoustics in Cancun, Mexico, 2-6 December 2002. These papers were: "Analysis of time series data in the East China Sea generated from explosive sources" (Knobles *et al*, J.Acoust Soc. Am.**112**(5), Pt.2, 2361 (2002)]), which, by inversion, determined bottom geoacoustics and forward propagation; "Mechanisms for the Asian Sea International Acoustics Experiment East China Sea reverberation measurements" (Dorfman *et al*, J.Acoust Soc. Am.**112**(5),

Pt.2 2254 (2002)), which reviewed ASIAEX bottom scattering strength determinations and their frequency and grazing angle dependence; and "Comparison of East China Sea low frequency bottom scattering strength determinations" (Cable *et al*,. J.Acoust Soc. Am.**112**(5), Pt.2, 2362 (2002)]), which compared scattering strength determinations obtained in ASIAEX with those obtained by the HEP and MAASW(DT) program data and indicated theoretical implications of results. A journal article, "On Shallow-Water Bottom Reverberation Frequency Dependence," has been prepared for submission to the IEEE J. Oceanic Eng. special issue on ASIAEX. Subsequently we have held back publication of this manuscript in order to include analysis of additional ASIAEX East China Sea reverberation data received by us in July 2003. Resubmission of the expanded article is planned for October 2003.

RESULTS

The variation of integrated bottom scattering strength determinations for the East China Sea, averaged over four transmissions and a 500 m range interval, are shown in Figure 1. As noted above, there is uncertainty regarding the persistence of nonlinear source effects influencing the derived frequency dependence of derived scattering strength estimates. For this reason different source spectra based on the Wakeley explosive source waveform model [4], representing different hypotheses concerning persistence of source finite amplitude effects, were used to analyze the ASIAEX reverberation data and derive scattering strengths. The different curves corresponded to estimates using the Wakeley source spectrum [4] with short range finite amplitude dominance (Wakeley short), and long range finite amplitude dominance emphasizing either medium attenuation losses (Wakeley long) or emphasizing finite amplitude effects (Wakeley finite amp.). Also shown is an estimate based on a Hannay and Chapman measured spectrum (Chapman)[5]. With the uncertainty in bottom scattering strength associated with source finite amplitude effects in mind it can be concluded from the figure that bottom scattering strength increases with frequency above 300 Hz at a power of frequency between 2 and 3. Below 300 Hz there is a change in frequency dependence with a weaker dependence of strength on frequency. There is a suggestion of an extremum (local maximum) in the scattering strength at about 175 Hz.

We have shown that this behavior of the derived bottom scattering strength is consistent with two scattering mechanisms, one dominant at the higher frequencies and the other at the lower end. Our modeling [1] has indicated that the strong frequency dependence at the band high end can be associated with small-scale volume scattering within one wavelength of the water-sediment interface. At the low end of the band (below 200-300 Hz) we have proposed that the scattering strength is dominated by scattering from rough sediment layering several meters below the ocean bottom.

These results have shown how a careful determination of the frequency dependence of reverberation-derived scattering strengths over a sufficient band can yield insight regarding the physical scattering mechanisms at work.
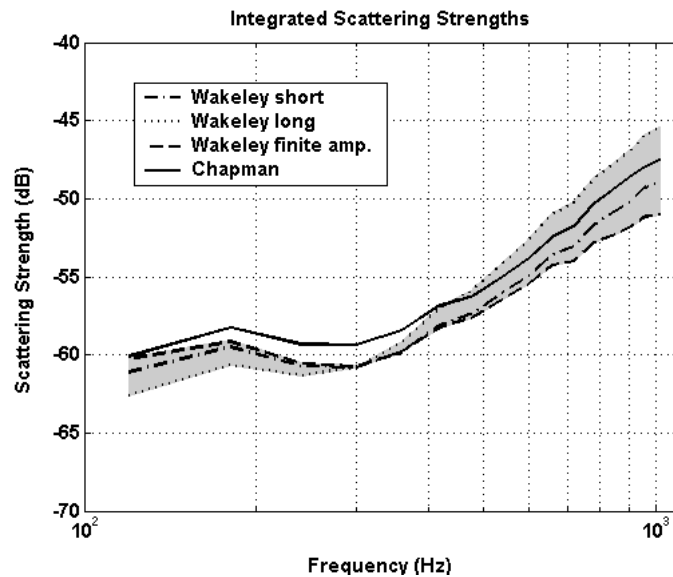
Figure 1. Integrated East China Sea bottom scattering strength estimates. The different curves correspond to short range finite amplitude dominance (Wakeley short), long range finite amplitude dominance controlled by medium attenuation (Wakeley long) or by finite amplitude effects (Wakeley finite amp.), and an estimate based on Hannay-Chapman spectrum (Chapman).

IMPACT/APPLICATIONS

Current low frequency shallow water reverberation models for sonar performance prediction use phenomenological bottom scattering strengths arbitrarily extrapolated from high frequency experience. There currently does not exist a model of shallow water reverberation that comprehends the reverberation results obtained in the DARPA Adverse Environments Program and in HEP littoral area surveys or that explains system performance achieved by Distant Thunder (DT) and EER in shallow water operations. Reverberation is the dominant factor in the operation of active sonars in shallow water, and to support mission planning and operational performance prediction for systems such as DT, LFA and EER, especially when HEP-type survey data are unavailable, there is a need for a bottom reverberation predictive capability requiring geoacoustic inputs such as those needed for propagation predictions.

RELATED PROJECTS

This research is being conducted jointly with David Knobles, ARL:UT and with Eugene Dorfman (BBN, Cambridge). In addition the long range reverberation ASIAEX studies of Renhe Zhang and Ji-Xun Zhou have responsibility for the data that have been used in the present research.

REFERENCES

[1] P. Cable, "Low frequency reverberation in continental shelf environments" Proceedings of the Fifth European Conference on Underwater Acoustics, ECUA 2000, P. Chevret and M. Zakharia, eds., paper 134, Lyon, France (2000).

[2]   D. Knobles, "Inversion of forward problem in extraction of bottom backscattering strength in shallow water," presented at the Shallow-Water Reverberation Focus Workshop, 25-27 August 1999, Santa Fe, NM.

[3]   P. Cable et al, "Reverberation-derived shallow water bottom scattering strength," IEEE J. Oceanic Eng. **22**, p 534-540 (1997).

[4]   J. Wakeley, "Coherent ray tracing – measured and predicted shallow water frequency spectrum," J. Acoust. Soc. Am. **63**, 1820-1823 (1978).

[5] D.E. Hannay and N.R. Chapman, "Source levels for shallow underwater sound charges," J. Acoust. Soc. Am. **105**, 260-263 (1999).